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~~**Summary Annual Report**~~

STATE AND NATIONAL ENERGY AND ENVIRONMENTAL RISK ANALYSIS SYSTEMS FOR UNDERGROUND INJECTION CONTROL

Contract Number:	DE-AC22-92MT92004
Contractor:	ICF Resources Incorporated
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Contract Date:	April 7, 1992
Anticipated Completion Date:	October 29, 1993
Government Award:	$194,792
Program Manager:	Michael L. Godec
Principal Investigator:	Mark R. Haas
Technical Project Officer:	Brent W. Smith U.S. Department of Energy Metairie Site Office
Reporting Period:	April 1992 - April 1993

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Executive Summary

ICF Resources' project, entitled "State and National Energy and Environmental Risk Analysis Systems for Underground Injection Control" includes two primary tasks (development of state and national systems respectively) and a technology transfer element. The state system was designed to assist states with data management related to underground injection control (UIC). However, during the current period, external changes (primarily pending regulatory changes at the federal level) have made the risk assessment protocol aspect of the state system of increased importance relative to data management. This protocol would assess the relative risk of groundwater contamination due to UIC activities in various areas of the state. The risk assessment system could be used to assist states in allocating scarce resources and potentially could form the analytical basis of a state variance program to respond to pending federal regulatory changes. Consequently, a substantial portion of the effort to date has been focused on this aspect of the project.

The national energy and environmental risk analysis system (EERAS) is designed to enhance DOE's analytical capabilities. This concept will be demonstrated using UIC data. The initial system design for EERAS has been completed but may be revised based on input from DOE and on the pending UIC regulatory changes. Data has been collected and organized and can be input once the file structure is finalized. The further development options for EERAS defined as part of this project will allow for the full development of the system beyond the current prototype phase which will enhance DOE's analytical capabilities for responding to regulatory initiatives and for evaluating the benefits of risk-based regulatory approaches.

Work on this project was delayed for several months due to the illness and death of our subcontractor, Mr. Troy Michie of Michie & Associates. Since Mr. Michie had performed all of the prior work upon which the state system was to be based, it was determined that no other subcontractor was capable of replacing his expertise. As a result, ICF Resources intends to perform all proposed activities with its own personnel. In addition to the loss of Mr. Michie's expertise, his contacts in Kansas and North Dakota (as a result of previous work there) may lead to consideration of alternative demonstration sites for the state system. Other than the delays and these possible changes, ICF Resources does not expect Mr. Michie's death to adversely affect the successful completion of the proposed effort.

Introduction

This project is designed to develop prototypes for two distinct analytical systems, one at the state level and one at the national level, that focus on data management for underground injection control. During this first year of the project, a substantial portion of the effort expended was focused on development of the state system. Initial scoping of the data requirements for the national system was also completed. These systems are described in greater detail in the Project Description section below.

Work on this project was delayed for several months due to the illness and death of our subcontractor, Troy Michie of Michie and Associates. Mr. Michie had performed the prior work on which the state system was to be based, leaving a gap that could not be filled by another subcontractor. Consequently, ICF Resources will be completing the entire proposed effort with its own personnel.

Project Description

As outlined in the contract statement of work, this project includes three primary tasks, each with several subtasks, as described below.

Task 1. *State Prototype UIC Information Management System.* The ICF Resources team will develop a state-level prototype system for managing UIC information on Class II injection wells, assessing risks of USDW contamination, and prioritizing data collection and risk assessment efforts based on consideration of both environmental risks and resource impacts. The structure previously developed by Michie & Associates will be supplemented with additional environmental information, where appropriate, along with resource characteristics information from TORIS. The concept and utility of this state-level UIC information management system will be demonstrated using data from the Williston basin of North Dakota, South Dakota, and eastern Montana. Guidelines for states implementing a UIC information management program based on the prototype will be documented and distributed with the proposed system.

> Task 1.1. *Identify System Requirements.* Using the information requirements developed by Michie & Associates as a starting point, the proposed effort will identify the items of information that would be desirable for a comprehensive state management program for UIC regulations. Data will be identified as to the practicality of its collection and importance to risk estimation in consultation with DOE and selected state regulators.
>
> Task 1.2. *Perform TORIS Data Assessment.* This subtask involves a determination of non-proprietary data currently available in TORIS that would be useful in estimating risks from underground injection and in determining future resource potential and location. This may include data items that were identified in Task 1.1, or items that could substitute for those identified. TORIS also includes data items essential to evaluating the resource potential in areas of concern that will assist in prioritization of data collection and risk assessment efforts and will supplement the information requirements developed in Task 1.1. For example, data in TORIS that may be incorporated into the proposed system include depth of producing formation, net pay thickness, porosity, permeability, clay content, dip angle, temperature, well

spacing, number of producing and injection wells in the reservoir, original oil-in-place, and remaining oil-in-place.

Task 1.3. *Assess Reservoir Data Availability.* This subtask will determine the availability of reservoir data by crosswalking TORIS reservoir locations with existing UIC data (from Michie & Associates) for the Williston basin. For gas reservoirs in the Williston basin, reservoir information (comparable to TORIS) which is reasonably accessible within the time frame and scope of this project will be obtained from state agencies and other sources (including operators, where possible).

Task 1.4. *Add Reservoir Information for the Williston Basin.* Work under this subtask will involve adding data elements to incorporate selected, non-proprietary TORIS reservoir data to the existing UIC information management system for the Williston basin previously developed by Michie & Associates, along with potentially adding reservoirs not currently in TORIS. This will include coding the reservoir data associated with each well, setting up a separate file for the reservoir data, and linking these data with existing UIC data for use in reporting and analysis. This will also include the design and development of any new reports for displaying reservoir data that would be useful to the state UIC program administrator.

Task 1.5. *Develop Generalized "Shell" UIC Information Management System.* Under this subtask, a "shell" UIC information management and risk assessment structure will be created by using the Williston basin system developed in Task 1.4 and by implementing modifications determined to be necessary and appropriate to create a generalized state-level system for UIC information management that may incorporate the items identified in Task 1.1. This development will include significant interaction with state regulators and others, as discussed in Section 2.2 in this proposal.

Task 1.6. *Develop State Risk Assessment Methodology.* This subtask involves identifying and prioritizing data elements important in estimating the risk of USDW contamination. In addition, using the Michie & Associates methodology for risk assessment for injection wells (Michie, 1988; Michie, 1990) and the ICF methodology for estimating risks from abandoned wells in the vicinity of an injection well (ICF, 1990), the proposed team will develop a simplified methodology using information available from TORIS and other existing sources. More than one methodology may be developed if necessary, based on variable quality and extent of information currently available at the state level. Risk assessments based on limited information may be less accurate, but can provide a means for identifying areas of greatest concern to prioritize state information collection or risk management efforts.

Task 1.7. *Test State Risk Assessment Methodology.* The proposed risk assessment methodology will be tested for predictability using data from the Williston basin system developed in Task 1.4. Results from the new methodology will be compared against the Michie & Associates methodology which uses more comprehensive information. If sufficient data are available, the new methodology will also be tested using the data compiled by Michie & Associates in the Kansas UIC information management project. Selected state regulators will be asked to comment on the utility of the proposed methodology and test it using existing state data. Based on these comments and comparisons, the new methodology will be modified as required to improve predictability using available data.

Task 1.8. *Document State Implementation Guidelines*. Under this subtask, the proposed team will document guidelines for the development and implementation of a state-level UIC information management and risk assessment system based on the generalized "shell" structure developed in Task 1.5. These guidelines will describe data requirements, hardware and software needs, steps that may be required to modify the "shell" for application to a particular state's needs, considerations in converting information from existing state sources to the new analytical system, recommended additional information that could be collected through modified state injection reports or permits, and options for prioritizing data collection or system implementation efforts given budgetary limitations. Development of the guidelines will include interaction with state regulators to identify their areas of concern and current data availability.

Task 2. *Preliminary National EERAS*. This task involves developing a preliminary national energy and environmental risk analysis system (EERAS). Part of the proposed effort will require developing methods to link EERAS with the existing TORIS database and analytical models. An analytical methodology for nationwide estimation of potential for USDW contamination from underground injection and the current and future resource potential associated with these areas of concern will be developed. Data from existing sources relevant to UIC risk analysis will be incorporated into the proposed EERAS. The proposed effort will also include identifying and documenting options for expanding data coverage in EERAS for UIC and other issues, suggesting ways of prioritizing data collection and R&D efforts, and recommending analytical methods that could be developed for performing energy and environmental impact assessments.

Task 2.1. *Identify EERAS Analytical Needs and Initial Structure*. In consultation with DOE, the proposed team will design a structure for the information and analytical methodologies that DOE would need to respond to regulatory and policy initiatives. A flexible database structure for managing environmental data at the reservoir-level, field-level, county-level, and basin-level will be designed and developed. Environmental parameters in the database may include the subsurface setting or surface location (such as an area with high corrosion potential or a wetland area), data on environmental risks, costs of environmental compliance, etc. A methodology will be developed for linking TORIS and EERAS to utilize the most disaggregate-level information available in an analysis, but simultaneously maintain system flexibility and ease of use. The database structure and linking methodology will be developed in consultation with DOE personnel, to assure that the framework meets DOE's requirements, is flexible enough to accommodate future enhancements beyond primarily UIC issues, and is compatible with existing DOE analytical systems.

Task 2.2. *Assess UIC Data Sources and Availability*. Under this subtask, the proposed team will determine the key data for development of a system to analyze risks of USDW contamination from underground injection at the national level. Information needs to develop a comprehensive UIC risk analysis system (including those that go beyond the scope of this project) will be identified, ranked, and documented, in consultation with DOE.

Task 2.3. *Add Locational Coordinates in TORIS*. Locational coordinates will be needed to cross-reference the reservoir information in TORIS with the environmental database structure created in Task 2.1. The most appropriate method for adding a geographic cross-reference to TORIS will be developed in consultation with DOE. A basin code for each reservoir will also be added to TORIS.

Task 2.4. *Input UIC-Related Environmental Data to EERAS.* This subtask involves collecting and inputting UIC-related environmental data to the EERAS structure from Task 2.1 based on the priorities established in Task 2.2. Complete, detailed reservoir-level coverage for the nation is not possible within the time and scope of this effort. However, selected regions such as the Williston basin will have more complete data to demonstrate the utility of the structure and test the linking and analytical methodologies developed. Some of the data that may be added to EERAS within the scope of this subtask include (sources of these data are shown in parenthesis):

- Estimated depth of deepest USDW (Gruy, 1989)
- Corrosivity probability data (Michie, 1988)
- Number of injection wells (Gruy, 1989)
- Number of abandoned wells (Gruy, 1989)
- Depth of surface casing (Gruy, 1989)
- Depth of perforation (Gruy, 1989)
- Average depth of injection zone (Gruy, 1989)
- Average depth of producing zone (Gruy, 1989)
- Estimate of abandoned wells per acre and within typical AOR (Gruy, 1989)
- Percent of injectors with short surface casing (Gruy, 1989)
- Produced water volumes by county (Michie, 1988)

Task 2.5. *Develop National Risk Assessment Methodology.* Building on the analytical methodology developed under Task 1.6, work under this subtask involves developing analytical methodologies for estimating national level risks for USDW contamination from underground injection. The methodology will draw on reservoir-, field-, county-, and basin-level information, using the most disaggregate data currently available in EERAS for each parameter in risk estimation calculations. In addition to the estimated level of risk for USDW contamination, the methodology will be used to estimate the resource potential associated with specific areas of concern.

Task 2.6. *Perform Risk Assessment for UIC.* An assessment of the nationwide potential for USDW contamination from underground injection, including current and future resources affected, will be performed using the methodology developed in Task 2.5. The proposed work will identify and document areas, if any, with large future enhanced recovery potential that have moderate to high risk of USDW contamination from underground injection. These areas may merit further analysis or information collection by DOE, EPA, and the states. This risk assessment will also serve as a test of the proposed methodology, which will be revised as appropriate to reflect any improvements or limitations discovered during performance of the assessment.

Task 2.7. *Evaluate Further EERAS Development Options.* This subtask involves identification of the data requirements and analytical tools required for a more detailed assessment of nationwide UIC contamination potential to meet the needs outlined in Task 2.1. Possible areas for future research will also be identified to expand EERAS beyond UIC issues to incorporate other environmental concerns. Analytical methods that could be developed using EERAS and TORIS to determine energy and environmental impacts of proposed policies, regulatory initiatives, or compliance strategies will also be documented. Finally, options for incorporating assessments of the impact of proposed policy and regulatory initiatives on current and future natural gas potential will also be identified under this subtask.

Task 3. *Technology Transfer*. The proposed technology transfer effort begins by identifying the audience for the state prototype UIC information management system. This would include determining which agencies or officials in each state are responsible for developing and administering UIC regulations. The appropriate technology transfer mechanisms for disseminating the research results to each audience will be assessed. Technology transfer efforts include a dialogue between the proposed team and the audiences identified. Reports, presentations, and papers for communicating research results will be prepared specific to each audience. Attendance at meetings such as those of the UIPC or IOCC, will provide an opportunity to receive feedback on research progress from state and federal regulators.

Task 3.1. *Identify Audience for Prototype Systems*. Under this subtask, the agencies or officials with responsibility for UIC in each state will be determined. These are the primary transfer audience for the state prototype system. DOE and other federal agencies are the primary audience for EERAS. Oil and gas operators, particularly independents, are also an audience for the products of the proposed effort. The appropriate methods for transferring project results to interested parties will be identified and refined over the course of the proposed project.

Task 3.2. *Solicit Audience Input in Product Development*. Solicitation of input from those who will be expected to use the results of this project is important to the development of effective systems. Much of this interaction is identified as part of the preceding tasks, and in the technology transfer plan discussed in Section 2.2. But the importance of this function is underscored by its placement in this subtask, which will involve all planning and preparation of materials to be distributed as part of these interaction efforts. For example, as the prototype state UIC information management system structure is being developed (Task 1.5), a presentation of the preliminary design will be sent to a select group of state regulators with UIC responsibility for their review and comment. The selection of these officials will be performed in consultation with DOE. As the state risk assessment methodology is developed (Task 1.6), an interim report will be distributed to the selected state regulators for their input on the utility of the methodology and whether the proposed information required is readily available in their state.

Task 3.3. *Distribute State Prototype*. Description of the state prototype system resulting from the proposed research will be presented at the UIPC or IOCC annual meeting or other forums determined to be appropriate. Attendance at state/industry meetings such as IOCC and UIPC will allow work-in-progress and research results to be discussed with key state and industry personnel to obtain their feedback. In addition to these meetings, the state prototype UIC information management and risk assessment system will be distributed to interested personnel in each state, along with the report providing guidelines for implementation. This transfer will utilize on-going relationships with the UIPC and IOCC, as well as other methods identified in Task 3.1.

Task 3.4. *Prepare Papers Summarizing Results*. Paper(s) summarizing the results of the proposed work will be prepared for submission to professional journals and symposia. DOE will be given the opportunity to review and participate in the preparation of these papers.

These papers will be targeted to the secondary transfer audiences for both the state prototype and EERAS.

Task 3.5. *Prepare EERAS Documentation.* The current status, database structure, analytical methodologies, and operation of EERAS will be documented and transferred to DOE. This documentation will consist of an interim progress report, a draft final report, and a final report. DOE and others will be provided opportunity to comment on the work throughout the effort, by reviewing these reports, along with the other progress reports required under this effort (discussed below).

Task 3.6. *Meet Reporting Requirements.* All DOE monthly, quarterly, and final reports will be prepared and submitted in a timely fashion. In addition, an interim report on research results and a draft final report for review by experts knowledgeable in UIC issues will be prepared and circulated for comment. The input received from these external reviewers will serve to assist the proposed team in developing a higher-quality final report and products for DOE.

Project Status

Most of the effort to date has focused on development of the state system prototype, especially the risk assessment aspects. Potential changes in federal regulatory requirements have enhanced the need for the proposed risk assessment protocol, leading to our initial focus in this area. With the death of Mr. Michie, it has also been necessary to focus on the state system to determine how we would compensate for the loss of his expertise.

Initial design work and data collection have also been performed for the national EERAS system. Technology transfer on all aspects of the project has also occurred through meeting attendance, informal conversations with state regulators, and presentation of a paper on the state risk assessment protocol. Progress on specific subtasks are described in the following paragraphs.

Tasks 1.1 and 1.2 have been completed. Substantial effort has been invested in Task 1.6. A technique for developing the State risk assessment methodology has been defined, as described in the paper entitled "Class II Risk Assessment Protocol" (see Attachment A). However, the actual protocol has not yet been developed because the data needed has not yet been obtained.

Task 2.1 has been completed on a preliminary basis and will be refined based on DOE input. Tasks 2.2 and 2.3 have been completed. Data has been collected and organized for Task 2.4, but until the data file structure is finalized, it cannot be input to EERAS. Some characterization of further EERAS development options for Task 2.7 has been an outgrowth of work completed to date, but additional effort will be required to complete this subtask.

Conversations have been held with state regulators as part of Tasks 3.1 and 3.2. With the death of Mr. Michie, who had previously worked with Kansas and North Dakota, it may be necessary to consider alternative states for participation and/or demonstration of the state prototype. Under Task 3.4, a paper on "Class II Risk Assessment Protocol" was prepared and presented at the Symposium on Class II Injection Well Management sponsored by the Underground Injection Practices Research Foundation (UIPRF). As an additional technology transfer function, at the TPO's request we held several discussions with the UIPRF and its contractors about coordination of efforts between our project and their DOE project which also concerns UIC issues.

Planned Activities

Completion of the project is anticipated within the next six months. The methodology for the state risk assessment protocol needs to be coded to create a working system, and the remainder of the state prototype developed and documented. Much of the effort will focus on finalizing the structure for the national EERAS and inputting the data that has been collected. Conversion of the state risk methodology to performing risk assessments on a national level will also be completed.

Summary

The EERAS being developed as part of this project will enhance DOE's analytical capabilities for responding to pending federal UIC regulatory changes. The potential future development of this system will continue to enhance DOE capabilities for analyzing risk-based regulatory approaches.

The impact of the state prototype is most likely to be the risk assessment protocol. It will assist states in the prioritization of scarce resources and may form the analytical basis for establishing a variance program under upcoming regulatory requirements. The data management functions of the system may be of less value to the states than was anticipated when the contract commenced due to events that have occurred in the interim.

Report Distribution List

Document Control Center
United States Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940, MS 921-118
Pittsburgh, PA 15227-0940

References

None

Publications

"Class II Risk Assessment Protocol," presented at the Symposium on Class II Injection Well Management is included as Attachment A.

Attachment A

CLASS II RISK ASSESSMENT PROTOCOL

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Abstract

Substantial volumes of brine, produced in conjunction with oil and gas, are reinjected to underground formations. Underground injection control (UIC) programs have been established under the authority of the Safe Drinking Water Act to protect underground sources of drinking water from contamination by subsurface injection. Managing the risks of contamination from injection operations is an important objective of state UIC programs.

Limited budgets often constrain state efforts to improve the quality and quantity of information available for the management of potential contamination risks from underground injection. Decisions on where to concentrate state resources in data management and field enforcement are often made subjectively. A risk assessment tool which explicitly characterizes the risk of contamination from injection operations can assist states in identifying and justifying regulatory and enforcement priorities. This paper describes the development process for a risk assessment protocol to explicitly characterize these risks which is compatible with existing data management programs and can be adapted for use by the states.

The *absolute* risk of groundwater contamination due to underground injection is quite low, often discussed in terms of occurrences per million well-years. In setting priorities, the *relative* risk of contamination of one area versus another area is more important than the absolute risk. The risk protocol to be developed will focus on the relative risk of contamination among various areas within a state.

The characterization of contamination potential from Class II injection wells involves:

- Identification of potential contamination pathways
- Definition of the factors affecting risk of contamination for each pathway
- Identification of possible data sources or analogs for each risk factor
- Characterization of the comparative importance of each factor affecting risk
- Computation of the relative risk of contamination.

Previous UIC-related risk assessments have focused on a single contamination pathway. The risk assessment protocol to be developed will incorporate alternative pathways in a comprehensive assessment of the potential risks.

The risk assessment protocol will be developed and tested with the assistance of state regulators. It will be based on commercial software and will provide explicit documentation of all assumptions, with the flexibility to adapt these assumptions to differing conditions. Development and testing of the risk assessment protocol is expected to be complete by April 1993.

A risk assessment protocol for characterizing the relative risk of groundwater contamination from Class II injection operations provides an explicit basis for incorporating risk-based decision-making into current state regulatory and data management programs. The benefits generated from use of an explicit methodology include prioritizing and justifying state activities, such as increased field activity monitoring, inclusion of fields in a computerized data management system, and collection of additional injection or production-related information.

Introduction

Oil and gas exploration and production (E&P) activities result in large volumes of produced brine that must be managed and disposed. Over 90% of this produced brine is currently reinjected into underground formations through Class II injection wells (Wakim, 1987). Two-thirds of this brine is reinjected to producing formations for pressure maintenance and enhanced recovery operations. The remainder is injected in saltwater formations below the base of the deepest potentially usable drinking water aquifers. Class II injection operations are regulated under the authority of the Safe Drinking Water Act (SDWA), which establishes minimum requirements for underground injection control (UIC) programs. UIC requirements were established to protect underground sources of drinking water (USDWs) from endangerment by subsurface emplacement of fluids. Twenty-two states currently have primacy for UIC operations; regional offices of the Environmental Protection Agency (EPA) administer UIC programs in the remaining states.

Need for Risk Assessment Protocol

Managing the risks associated with oil and gas injection operations requires substantial volumes of information about injection well operations, the history of well integrity testing, and geologic and hydrogeologic conditions. States are making substantial strides in the management of this UIC data, as recent and ongoing efforts demonstrate. However, limited budgets often constrain state efforts to improve both the quantity and quality of information available. Decisions on where to concentrate state resources, in the areas of both data management and field enforcement, are often made subjectively, based on anecdotal information or "experience." An explicit methodology for characterizing the relative risks of groundwater contamination from underground injection can assist states in optimizing the use of their limited resources and in establishing and justifying regulatory and enforcement priorities.

In 1989, EPA conducted a Midcourse Evaluation of UIC requirements under the SDWA, which identified several areas for further investigation. EPA convened a Class II Injection Well Advisory Committee to make recommendations about required program improvements. In early 1992, the Advisory Committee made its recommendations, which EPA will consider for rulemaking over the next 18-24 months.

One of the recommendations of the Advisory Committee was to extend the current area of review (AOR) requirements to Class II wells previously permitted by rule that have not already been covered by an AOR. The Committee recommended that states be allowed to establish a variance program for identifying areas where there is a sufficiently low risk of upward fluid movement from the injection zone that could potentially endanger USDWs. Wells granted a variance would be exempted from those AOR requirements. The Committee indicated that in establishing a variance program, states could consider:

- The absence of USDWs
- Whether the reservoir (injection zone) is underpressured relative to the USDW
- Whether local geological conditions preclude upward fluid movement that could endanger USDWs
- Other compelling evidence.

A risk assessment protocol can be used by states to provide an explicit basis for setting up a variance program, as well as for prioritizing state regulatory activities on the basis of relative risk.

The Underground Injection Practices Research Foundation (UIPRF) is currently sponsoring efforts to evaluate and assist current state UIC data management efforts. In the *Phase I Inventory and Needs Assessment* (CH2M Hill, 1992), state regulators contacted generally ranked "risk assessment and evaluation" and "determination of high-risk areas throughout the state" as high priorities. The risk assessment protocol to be developed addresses these issues and will be compatible with existing data management programs and risk assessment efforts.

Purpose of Paper

The purpose of this paper is to describe the objectives and preliminary design of a protocol to assess the relative risk associated with UIC operations. The work on which this paper is based is being sponsored by the U.S. Department of Energy (DOE), Metairie Site Office and is being performed by ICF Resources Incorporated. This project is on-going, and the design phase of the risk assessment protocol is just being completed.

Importance of Relative Risk

While casing corrosion and other mechanical integrity failures in injection wells sometimes occur, groundwater contamination as a result of these problems is extremely rare. The General Accounting Office (GAO) has reported finding 23 cases since 1970 where Class II injection operations are believed responsible for contamination of a drinking water aquifer (GAO, 1989). This compares with over 160,000 active Class II injection wells nationwide. Nine of the cases reported by GAO resulted from purposeful injection directly into a USDW, which would be a violation of existing law. Only a small number of reported occurrences of contamination are believed to be due to mechanical integrity failure or abandoned wells serving as a conduit for contaminants. In an earlier study based on data from Texas in the early 1970s, the Office of Technology Assessment (OTA) estimated that contamination had occurred only 2 times per 1 million well years (OTA, 1978).

Federal UIC program changes from the mid-1980s have been followed by increasing requirements at the state level. The implementation of new UIC requirements, by eliminating some of the prior problems and strengthening protection, has reduced the risk of future groundwater contamination below the levels observed by GAO and OTA. Thus, in absolute terms, the risk of groundwater contamination from Class II injection operations is quite low.

In establishing a variance program for AOR requirements or for prioritizing state regulatory efforts, the *relative* risk is more important than the *absolute* risk of contamination. Even an older producing area with numerous inadequately plugged abandoned wells and highly corrosive subsurface conditions is unlikely to have an occurrence of groundwater contamination due to injection. But the relative risk of such an area compared with an area discovered and developed after 1984 may be considerably higher. In allocating its limited resources, a state could reduce the potential that groundwater contamination would occur by focusing, in relative terms, on areas with the greater risk. The priority in this example is fairly obvious. But in many states the differences among fields will be painted in numerous shades of gray, and an explicit means for estimating the relative risk of contamination could assist in identifying and justifying priorities.

Previous Work on Risk Assessment from UIC Operations

Several previous analyses assessing the risk of groundwater contamination from Class II injection have been performed, including:

- Michie for API (1988)
- Michie for UIPRF (1989 and 1991)
- ICF Incorporated for EPA (1990)
- Warner and McConnell for API (1990).

Each of these analyses has expanded the knowledge base for estimating the risks associated with injection and the factors which contribute to that risk.

Michie's work for the American Petroleum Institute (API) resulted in a methodology for estimating the absolute risk of contamination if simultaneous failure of the tubing, production casing, and surface casing occurred. The methodology used historical data on casing and tubing failure rates and accounted for the corrosive potential of subsurface water in producing basins. This methodology confirmed that the absolute risk of groundwater contamination is quite low.

For the UIPRF, Michie linked his risk assessment methodology with a UIC data management system for the Williston Basin in North Dakota, South Dakota and Montana. Incorporating risk assessment with a data management system, this project demonstrated the utility of risk-based data management for UIC programs. Michie took this concept one step further in a project in Kansas sponsored by UIPRF, which included both producing and injection wells in the data management system.

ICF Incorporated developed a methodology for EPA that performed area-wide assessments of the risk of USDW contamination from abandoned wells in the vicinity of injection operations. The methodology considered such factors as the pressure differential, permeability, injection rate, radius of concern, and probability that an abandoned well existed within the radius of concern. The methodology resulted in a qualitative assessment of low, medium, or high risk. This methodology was field tested in Oklahoma and reviewed by the oil and gas industry, but project funding was discontinued before completion.

Warner and McConnell also focused on abandoned wells as potential pathways for groundwater contamination. They used finite differential numerical modeling to determine the extent to which brine might be forced into a USDW. This analysis included a detailed examination of wells in the Lower Tuscaloosa Sand of Mississippi and Louisiana. Modeling was based on scenarios of an uncased abandoned well and a cased abandoned well with casing corrosion. The analysis concluded that abandoned wells in this area were highly unlikely to serve as conduits for brine to reach USDWs.

Objectives of Risk Assessment Protocol

Building from this work, a protocol will be developed that can help better characterize the relative risk of contamination for use in allocation of limited resources, justification of a variance program, or other risk-based decision-making. The system's expected (and potential) applications define several general requirements/objectives:

- Areal Assessments. The protocol should perform areal assessments of the relative risk of contamination. In setting priorities, assessments of areas (such as a field) are more useful for high level appraisals than assessments of individual wells. However, to provide a high degree of confidence in the result, the area to be considered must be relatively homogeneous; areas larger than a field may be impractical. The methodology may also be applicable to an individual well, to assist in identifying potential concerns within high priority areas.

- Coverage. The protocol should incorporate the risk from as many potential contamination pathways as possible to provide a comprehensive assessment of the relative risk of groundwater contamination via different pathways within an area.

- Data Requirements. The protocol should require a minimum amount of readily available data to maximize the utility of the system to state regulators. Yet, where more data are available, the protocol should accommodate this information, improving the degree of confidence associated with the result.

- Explicit Assumptions. Any assumptions included in the protocol should be made explicit, and means should exist for the regulator to adjust these assumptions based on additional information, differing conditions, or to test sensitivities.

- Adaptability. While a single system cannot be developed that readily meets the needs of regulators in all producing states, the protocol must be easily adaptable to various states, to accommodate existing state data management systems.

Characterization of Contamination Potential from Class II Wells

The characterization of the contamination potential from Class II injection operations involves identification of potential contamination pathways, definition of the factors affecting risk of contamination for each pathway, identification of possible data sources for each risk factor, and characterization of the comparative importance of each factor affecting risk. Once these steps have been completed, a methodology to compute the relative risk of USDW contamination based on the identified risk factors can be developed.

Figure 1

Universe of Potential Contamination Pathways

	Outside Casing (Cement Failure)	**Inside Casing (Casing/Tubing Failure)**
Disposal Well		
Production/Injection (EOR) Well		
Abandoned Well		

Potential Contamination Pathways

Previous risk assessment efforts have focused on a single contamination pathway such as corroded casing or abandoned wells serving as the conduit for brine migration. To provide a comprehensive assessment of the risk, it is necessary to define the universe of potential pathways for contamination of a USDW from oil and gas injection operations. After considering possible well construction configurations, the potential contamination pathways can be simplified in a matrix such as that shown in Figure 1. Movement of brine from the injection zone to a USDW could occur either outside the casing or inside the casing. The factors associated with each of these would be dependent upon whether the well was a disposal well, a production/injection (EOR) well, or an abandoned well. An uncased abandoned well could fall into either of the bottom cells in the matrix with the factors altered to reflect absence of cement or casing rather than failure.

Factors Affecting Risk

The six cells shown in Figure 1 describe the potential means for brine to reach and contaminate a USDW. However, many factors would affect whether contamination could occur through each pathway described. Some factors would be common to all cells of the matrix, while others would be unique to a single cell. The factors associated with each cell will be used to define the risk of contamination through that potential pathway. Table 1 presents a preliminary list of the factors associated with each cell of the matrix. Data values may not be required for all of the risk factors included in Table 1, but in identifying those most important to the relative risk of contamination, it is important to consider broadly what factors may affect risk.

Potential Data Sources

The next step in characterizing the potential risk associated with Class II injection is to identify possible data sources for the risk factors in each cell of the matrix. This process will identify which data items are readily available from state data management systems (drawing on the needs assessment work for UIPRF), and other public and private information sources. In many states, existing data management systems contain much of the information needed to estimate the risk, including mechanical integrity test

Table 1

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Outside Casing in a Disposal Well

- Pressure in disposal formation
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Quality of cement job
  - Age of well
  - Hole size and casing size
  - Formation type
  - Type and volume of cement pumped
  - Pressure test results (direct measure of communication)
  - Cement bond log results (direct measure of micro-annulus or channeling)
- Number/density of disposal wells

Contamination from Outside Casing in a Production/Injection Well

- Pressure in injection formation
  - Depth and/or degree of over or under pressure (if any)
  - Volume of injected fluids or produced fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and injection formation
- Quality of cement job
  - Age of well
  - Hole size and casing size
  - Formation type
  - Type and volume of cement pumped
  - Pressure test results
  - Cement bond log results
- Number/density of production/injection wells

Contamination from Outside Casing in an Abandoned Well

- Pressure in disposal/injection zones penetrated by abandoned well
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal/injection formation
- Abandoned well characteristics
  - Age
  - Plugging/casing/completion practices
  - Plugging materials
- Quality of cement job
  - Age
  - Hole size and casing size
  - Type and volume of cement pumped
  - Pressure test results
  - Cement bond log results
- Number/density of abandoned wells
- Distance from disposal/injection well

Table 1 (Continued)

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Inside Casing in Disposal Well

- Pressure in disposal formation
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal formation
- Completion configuration
  - Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of disposal wells

Contamination from Inside Casing in Production/Injection Well

- Pressure in injection formation
  - Depth and/or degree of over or under pressure (if any)
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and injection formation
- Completion configuration
  - Tubingless or packerless
    - Number of casing strings
    - Age of well
    - Production history (pressure, sand, rates)
    - Produced fluid corrosivity (CO_2, H_2S)
    - USDW water composition
    - Casing strength, material, condition (new or used), size
  - Tubing and packer
    - All factors identified for tubingless or packerless
    - Tubing strength, material, condition (new or used), size
    - Packer type
    - Type of annular fluid
  - Annular disposal
    - All factors identified for tubing and packer
    - Surface pressure on annulus/injection rate
- Use of cathodic protection
- Number/density of production/injection wells

Table 1 (Continued)

Major Risk Factors for Each Potential Contamination Pathway

Contamination from Inside Casing in Abandoned Wells

- Pressure in disposal/injection zones penetrated by abandoned well
  - Depth
  - Volume of injected fluids
  - Capacity of formation (kh)
- Pressure in USDW
  - Depth
  - Degree of depletion/recharge
- Vertical distance between USDW and disposal/injection formation
- Abandoned well characteristics
  - Age
  - Plugging/casing/completion practices
  - Plugging materials
  - Annular fluid
- Corrosion potential
- Number/density of abandoned wells
- Distance from disposal/injection well

histories, injection rates and pressures, depths, and well construction. Aquifer data can be difficult to obtain; however, in the needs assessment survey, 17 of 25 states contacted reported having data on the general location and depth of aquifers. In other states aquifer information may be available from water well operators, examination of well logs for producing wells in the area, or from the U.S. Geological Survey.

For data items which are not readily available, analogs from available information, engineering "rules of thumb," or computer regressions/simulations will be developed. Many data parameters (such as corrosion potential or density of abandoned wells) have been estimated on a more aggregate basis (see Michie, 1988 and Gruy, 1989). These data could be used in a risk assessment if more area-specific (field-specific) information was not available. Potential state-specific sources of information will be documented as part of the implementation guidelines provided to states with the risk assessment protocol.

Importance of Each Factor

Information must also be developed on the relationships between the risk factors identified and the comparative importance of each factor to the potential for contamination. In addition to articles in the literature, potential data sources include oilfield service companies, producing companies, and state regulators' experience. Consultations with field personnel should yield insight into the relationships between the various factors that can be used in constructing the analytical methodology.

To the extent possible, the relationships developed will be based on field experience with mechanical integrity or cement failures where no groundwater contamination occurred. Analysis of the conditions that prevented contamination is the best source of information about which factors are most important to the risk of contamination. Pressure differentials between the injection formation and the USDW that would allow or prohibit upward movement of brine are clearly the most important risk factor in most cases. Rankings of the relative importance of other risk factors will be developed using historical data (with regressions or simulations as appropriate) as well as standard engineering correlations and the judgment and extensive field experience of oil and gas company personnel, service company personnel and state regulators. Assumptions made about the relationships between and comparative importance of risk factors in the analysis will be made explicitly and documented; users of the protocol will be able to adjust these assumptions to the needs of a particular state or to test an alternative assumption.

Computation of Relative Risk

Risk will be defined as a function of the risk factors identified, using the comparative importance relationships developed. Some of the risk factors will be measured quantitatively (such as pressure differential or vertical distance brine must travel), while others will be qualitative (such as the quality of the cement job or use of cathodic protection). Qualitative measures will be converted to a numerical scale to provide a common basis for combining diverse information in an equation to calculate risk. The relative importance of each risk factor will provide the weighting for each term in the equation in developing the protocol. Another important consideration in the development of the protocol is the uncertainty associated with parameter estimates (both the areal estimates input by the user and the factor relationships developed). The effect of this uncertainty on the level of confidence in the result must be addressed. The risk assessment protocol will identify the relative risk on a numerical scale (e.g., 1 to 5). A scale of this type will provide the type of comparability among pathways/areas desired in a format that is easy to understand and is appropriate for the variability and ranges of uncertainty involved.

The risk assessment protocol will calculate the relative risk of contamination two ways: (1) for each potential pathway of contamination (cells in the matrix), and (2) for the area as a whole considering all potential contamination pathways. The relative risk of contamination in an area through each of the potential contamination pathways will be useful to states in identifying priorities within an area. These relative risk ratings will also be combined to develop a single risk assessment for an area which will allow various areas to be compared in setting state-wide priorities or establishing a variance program.

Development of Risk Assessment Protocol

Development of the risk assessment protocol will follow the steps outlined above for identifying data sources and developing relationships among the risk factors so that the relative risk of contamination can be calculated. Several alternative statistical techniques will be evaluated for developing the protocol and for accounting for uncertainty.

In developing the risk assessment protocol, ICF Resources will work extensively with state regulators to assure that the system addresses their concerns and provides useful results. ICF Resources will also work with on-going data management efforts to address risks from UIC to assure the compatibility and maximize the utility of the protocol to the states.

Format for Protocol

The platform on which the protocol is to be designed has not been determined. The risk assessment protocol will be IBM or compatible PC-based and will use commercial software or stand alone.

Several commercial software packages are being considered, including Lotus 1-2-3 and dBase III/IV. The objective is to make the system easy to use and adaptable, with the assumptions explicit, easily modified, and thoroughly documented.

Testing and Sensitivity Analysis

Field testing of the risk assessment protocol will be conducted in cooperation with 1 or 2 states, perhaps reflecting states with and without well-established data management capabilities. The expertise of the regulators in these states will be solicited throughout the development process, as well as in testing and validation of the protocol. Calibration of the protocol will be subjective because (1) the paucity of actual contamination occurrence data makes history matching impossible, and (2) many of the risk factor relationships may be subjective rather than empirical.

Sensitivity analyses will be run as part of the testing and validation process to identify factors or assumed relationships with the greatest impact on the result. These factors and relationships will determine areas where better data or further study may be required to increase the confidence level of the resulting risk assessment.

Schedule for Completion

The design phase of this project is just being completed. States participating in the development and testing phases of the project will be identified within the next month. Information collection for several aspects of the development has already started and will continue over the next two months. Development and testing of the risk assessment protocol is expected to be complete by April 1993.

Conclusions

A risk assessment protocol for characterizing the relative risk of groundwater contamination from Class II injection operations provides an explicit means for incorporating risk-based decision-making into current state regulatory and data management programs. A risk assessment protocol can be used for exempting wells with a low risk of contamination from a potential extension of current AOR requirements or for prioritizing and justifying state activities, including:

- Increased field activity monitoring
- Inclusion of fields in a computerized data management system
- Collection of additional injection and production-related information.

The value of incorporating risk-based decision-making into state UIC programs is obvious. An explicit methodology that provides a comprehensive assessment of the potential risk of contamination from all possible pathways is an appropriate tool for incorporating risk, and can generate benefits by allowing limited resources to be focused on those areas where they can have the greatest impact on reducing contamination risks.

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